A complete model of CH^+ rotational excitation including radiative and chemical pumping processes

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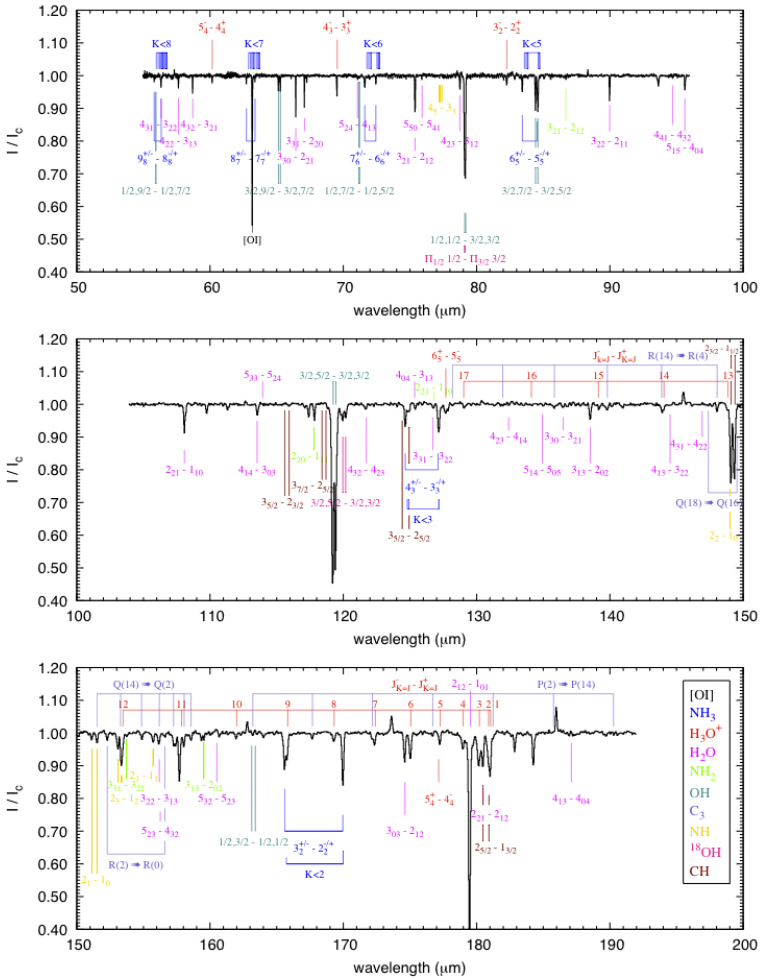
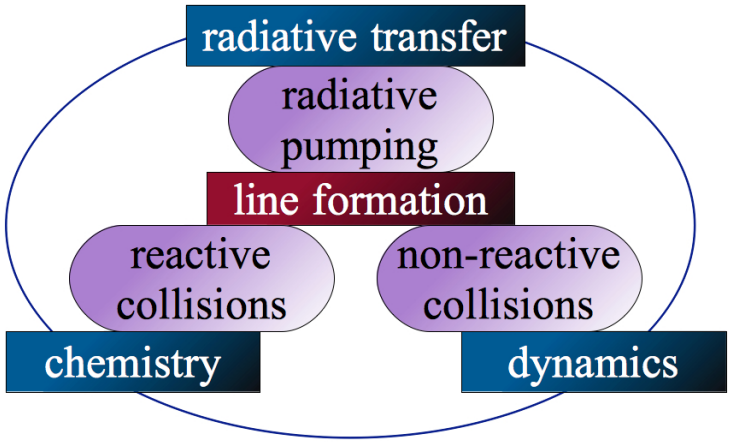


Herschel/PACS - SgrB2(M)

find minimal nb of components

- density
- kinetic temperature
- velocity field
- abundance

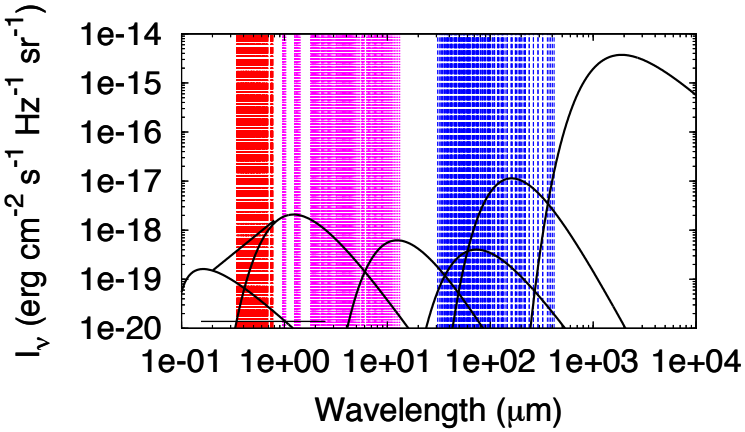


	Orion Bar		NGC 7027	
	$n_{\rm H}$	$T_{\rm K}$	$n_{\rm H}$	$T_{\rm K}$
OI (^{3}P$_1$-^{3}P$_2$), CI (^{3}P$_1$-^{3}P$_0$), C$^+$ (^{2}P$_{3/2}$-^{2}P$_{1/2}$), H$_2$ S(1)	5×10^4		2×10^5	
CO ($J < 9$)	10^5	85	2×10^5	$\leqslant 100$
^{13}CO ($J \geqslant 9$), CO ($J \geqslant 11$)	10^7	120	2×10^6	200
OH ($^2\Pi_{1/2}$,$^2\Pi_{3/2}$) CH$^+$ ($J \leqslant 6$)	10^7	200	2×10^6	1000
CO$^+$ ($2_{5/2} - 1_{3/2}$)	$\geqslant 10^6$		$\geqslant 10^6$	

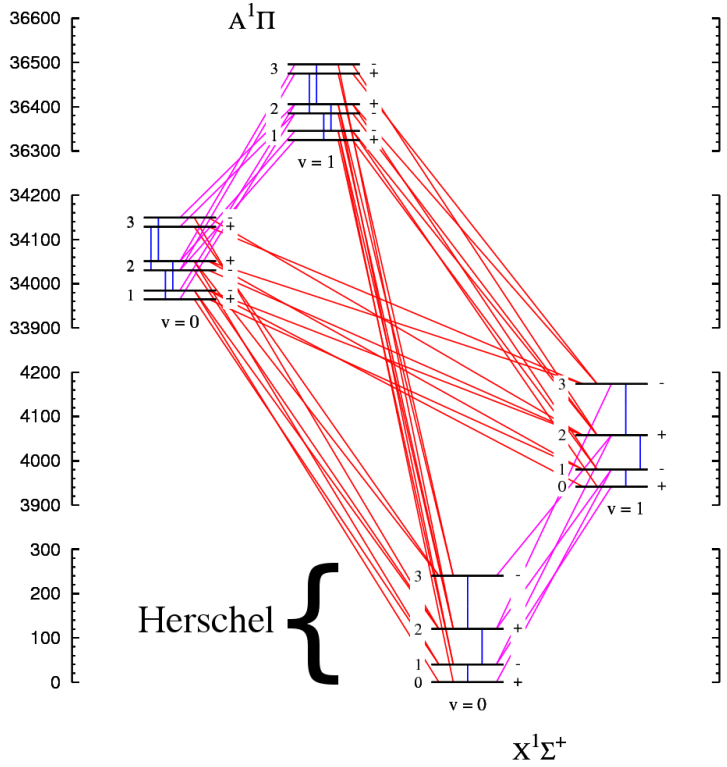
interclump medium + large density gradients/clumps

MADEX - LVG model

- spherical/plan-parallel cloud
- external radiation field
  - default : local ISRF
  - scaling : T, β, τ, χ

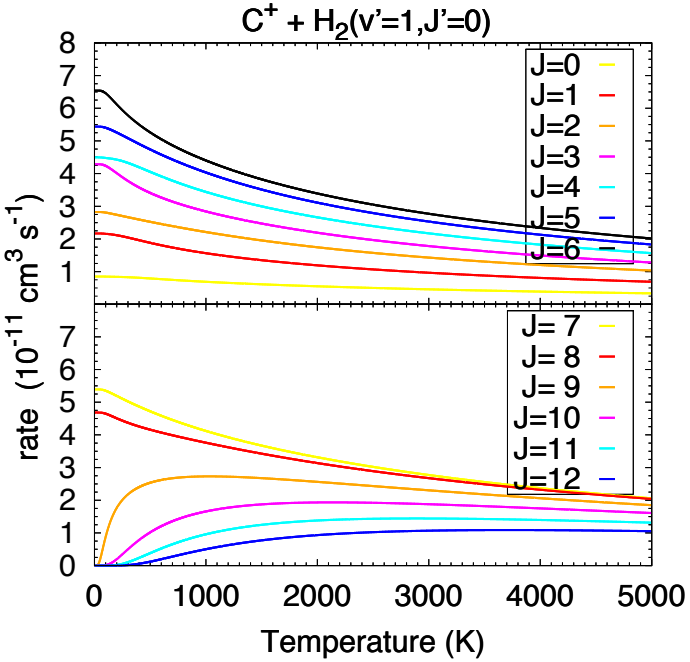


energy structure of CH^+



formation

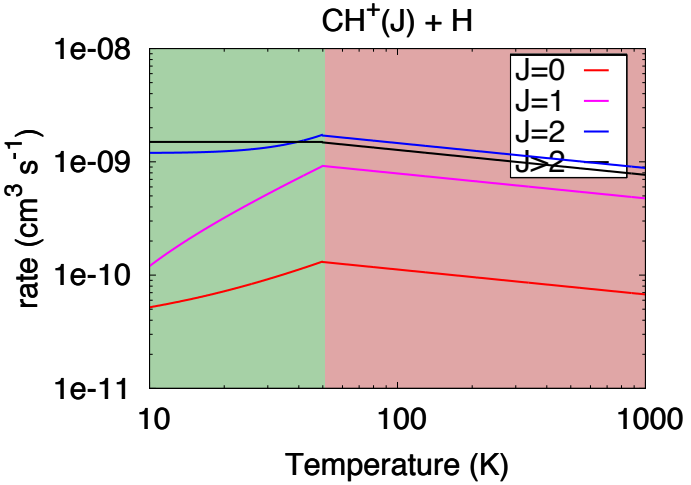
- $C^+ + H_2(v', J') \rightarrow CH^+(v, J) + H$
- others : $\propto (2J+1)\exp(-E_J/T_K)$



Zanchet et al. (in prep.)

destruction

- $CH^+(J) + H$
- others : J-independent



Plasil et al. (2011)

parameter domain

$$[\mathrm{H_2}] = 0.5$$

$$[e^-] = 10^{-4}$$

$$n_{\mathrm{H}} = 10^2 \rightarrow 10^6 \quad \mathrm{cm}^{-3}$$

$$T_{\mathrm{K}} = 10 \rightarrow 5000 \ \mathrm{K}$$

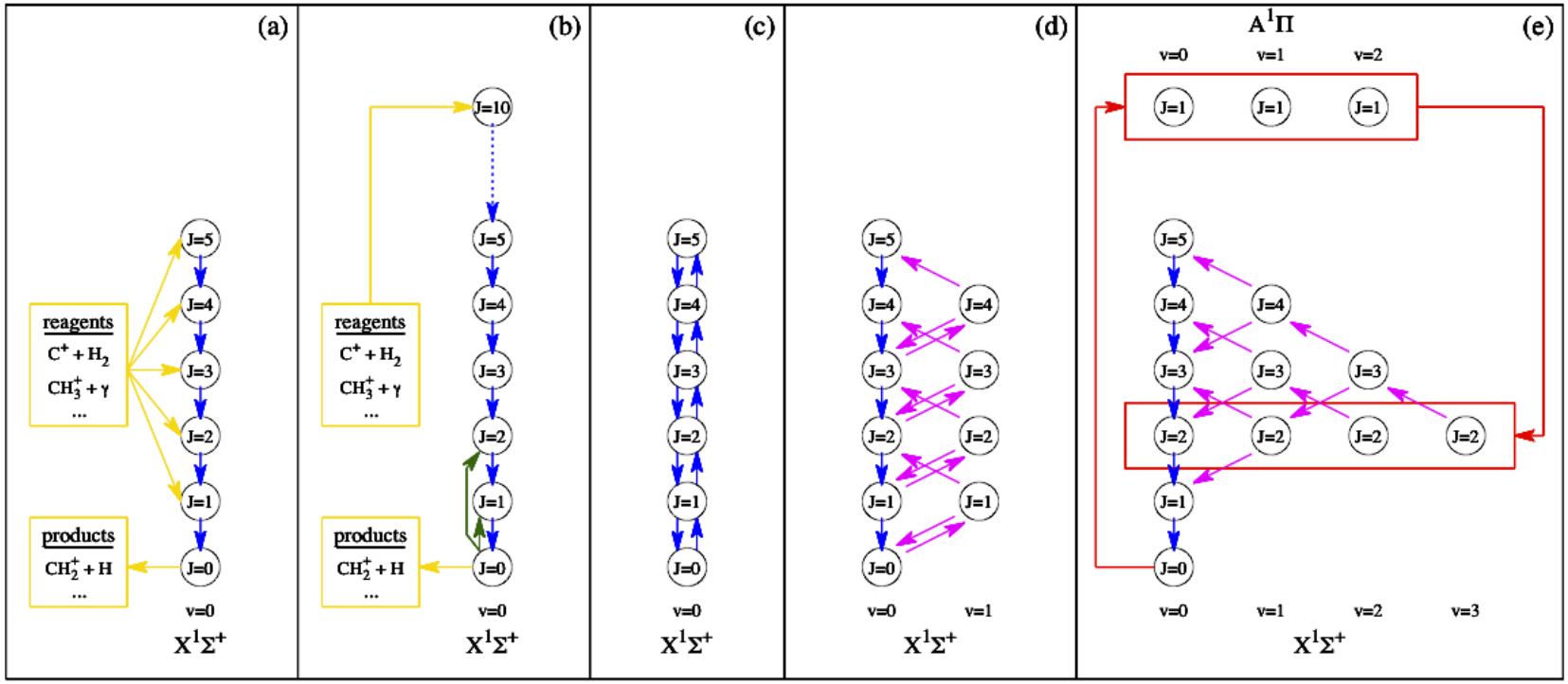
$$\chi_{\mathrm{fir}} = 10^3 \rightarrow 10^8$$

$$\chi_{\mathrm{nir}} = 10^5 \rightarrow 10^{10}$$

$$\chi_{\mathrm{opt}} = 10^2 \rightarrow 10^7$$

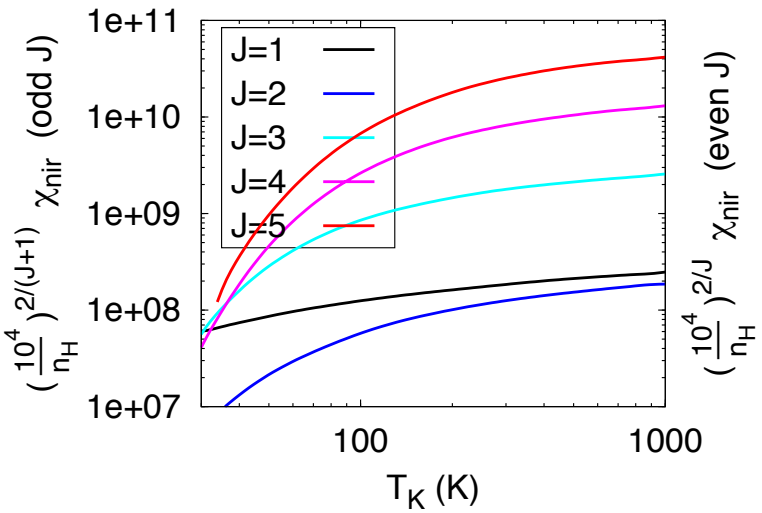
main excitation pathways

$T_{\mathrm{K}} = 100$ $T_{\mathrm{K}} = 1000$ $\chi_{\mathrm{fir}} = 10^6$ $\chi_{\mathrm{nir}} = 10^{10}$ $\chi_{\mathrm{opt}} = 10^6$



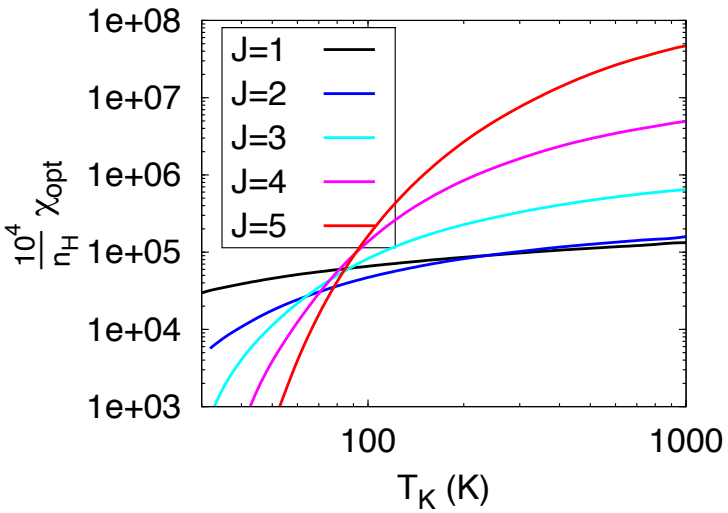
requirements to activate the radiative pumping

near-infrared pumping



$$\chi \propto [n_{\rm H}\ \exp(-E_J/T_{\rm K})]^{2/J}$$

optical pumping



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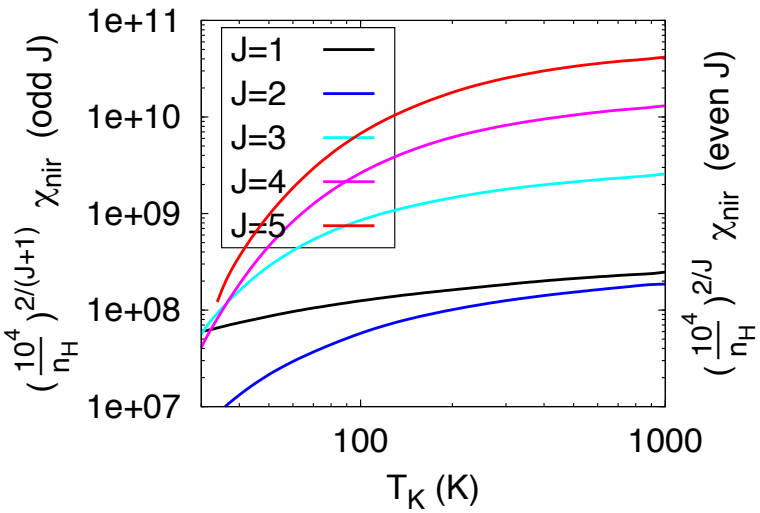

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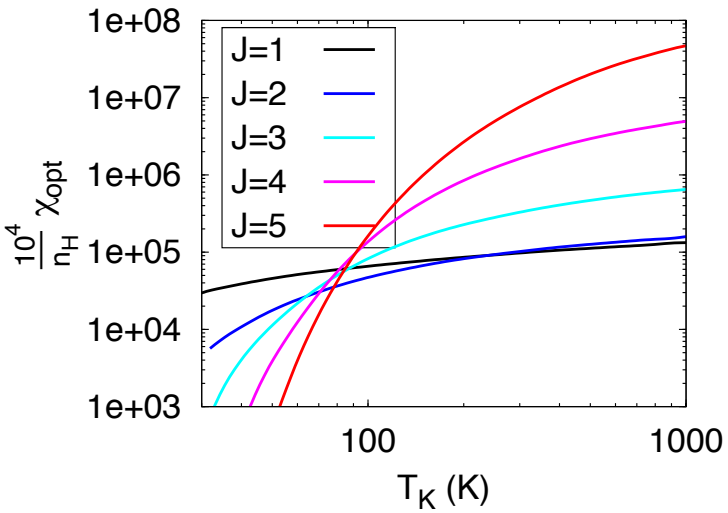
optical pumping



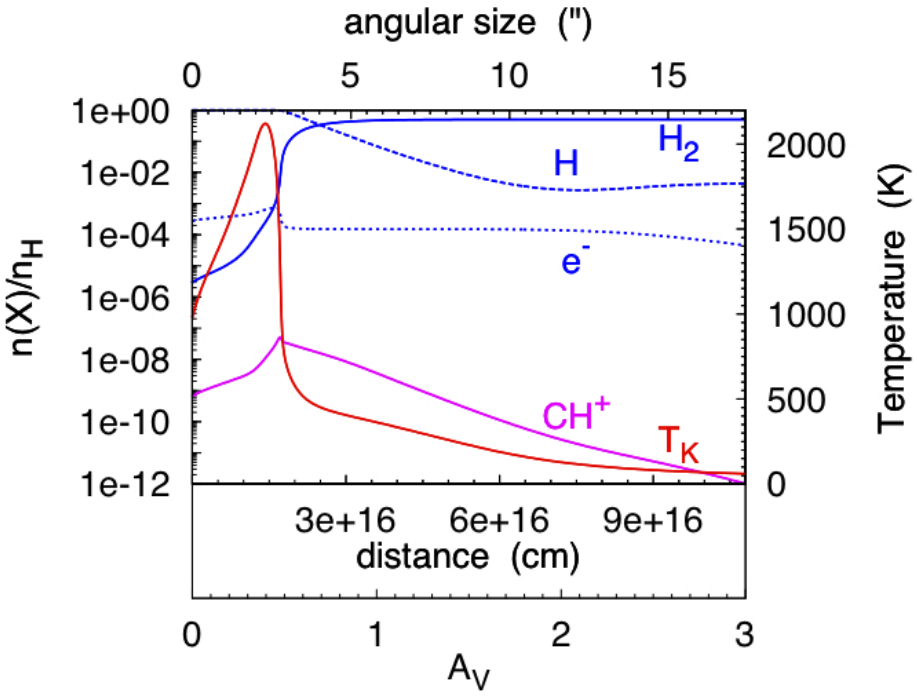
$$\chi \propto n_{\mathrm{H}}\ \exp(-E_J/T_{\mathrm{K}})$$

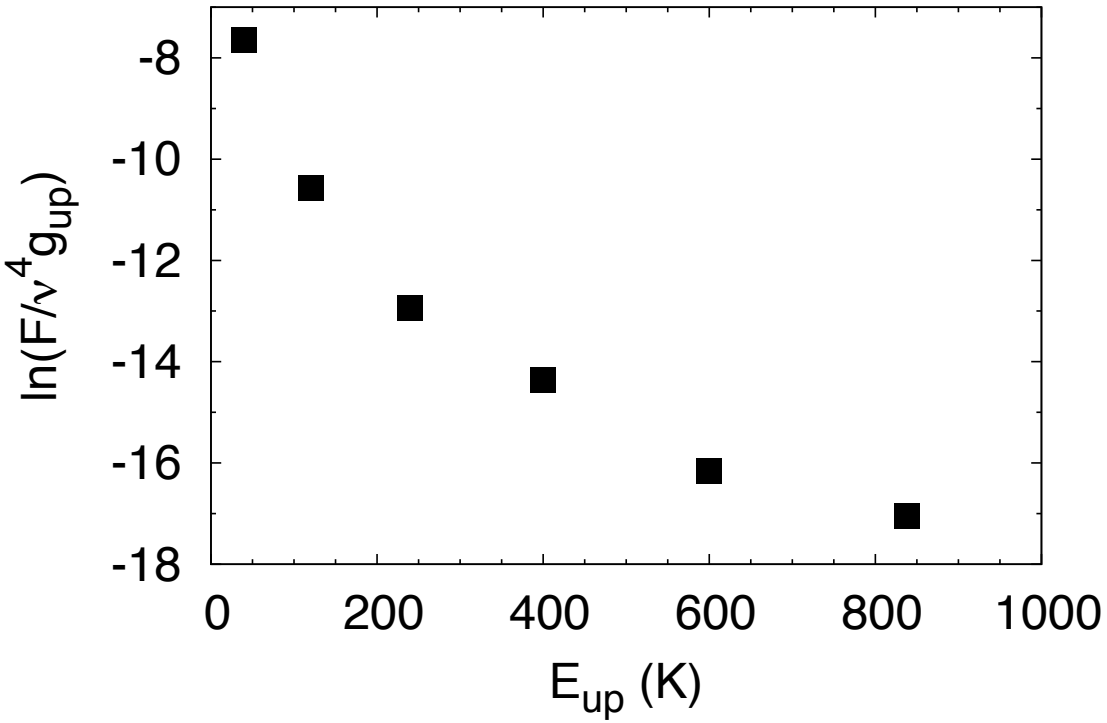
no interstellar clouds with these conditions

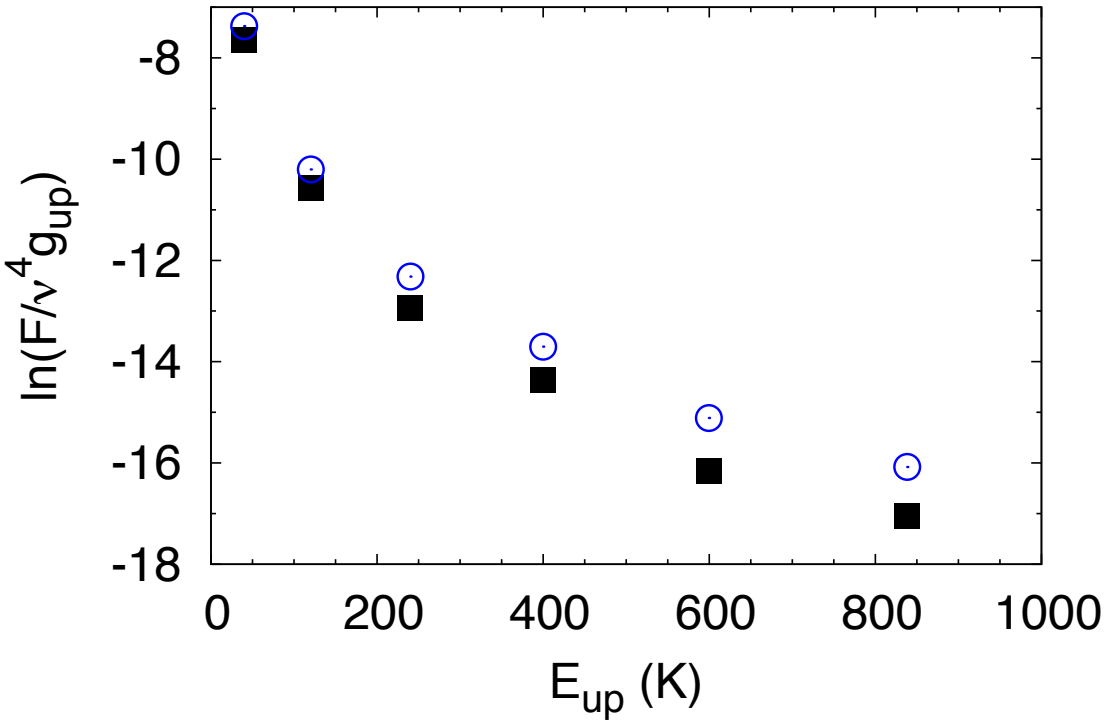
physical conditions

- $n_{\rm H} = 5 \times 10^4$ cm^{-3}
- $\chi_{\rm nir} = 3 \times 10^4$
- $\chi_{\rm opt} = 3 \times 10^4$

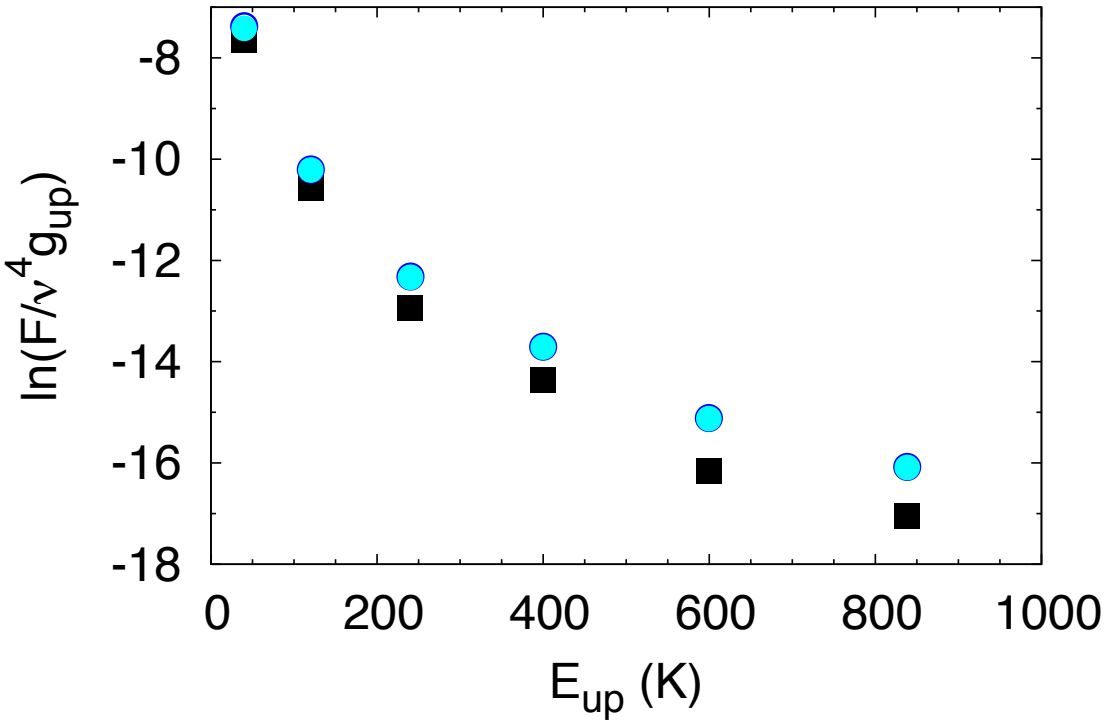
chemical profiles




-8
-10
-12
-14
-16
-18
0
200
400
600
800
1000
ln(F/ν^4 g_up)
E_up (K)



- chemical pumping dominant : $J \geqslant 3 - 2$



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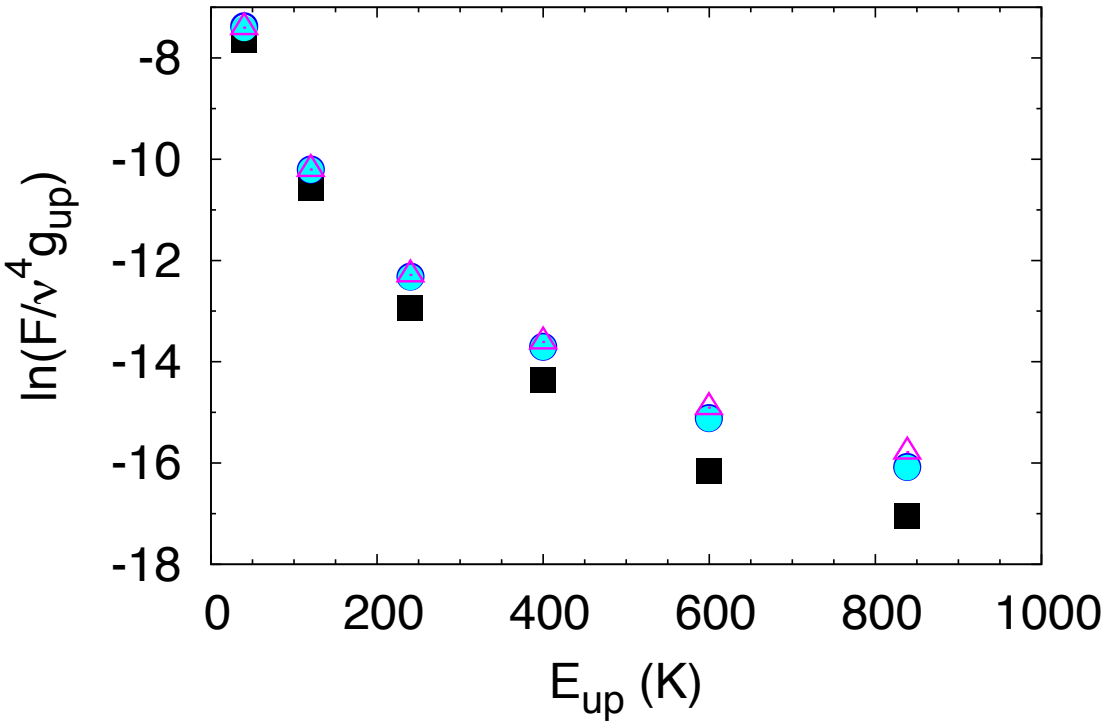

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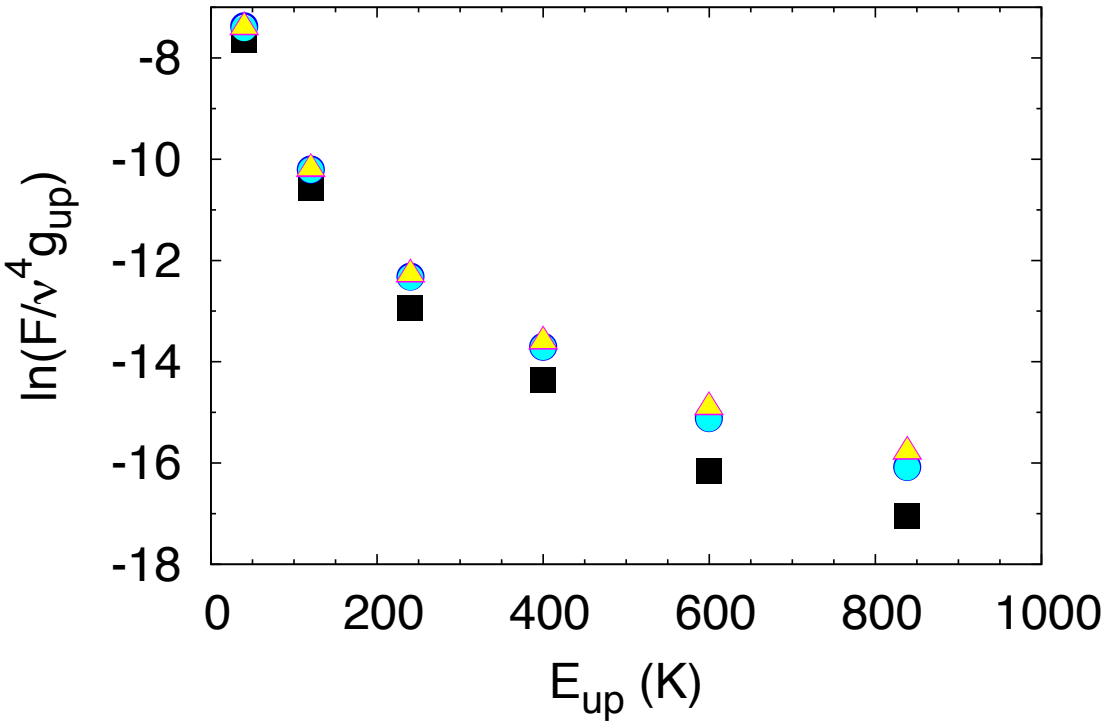
- Zanchet's rates : $> 30\%$ on $J \geqslant 5-4$



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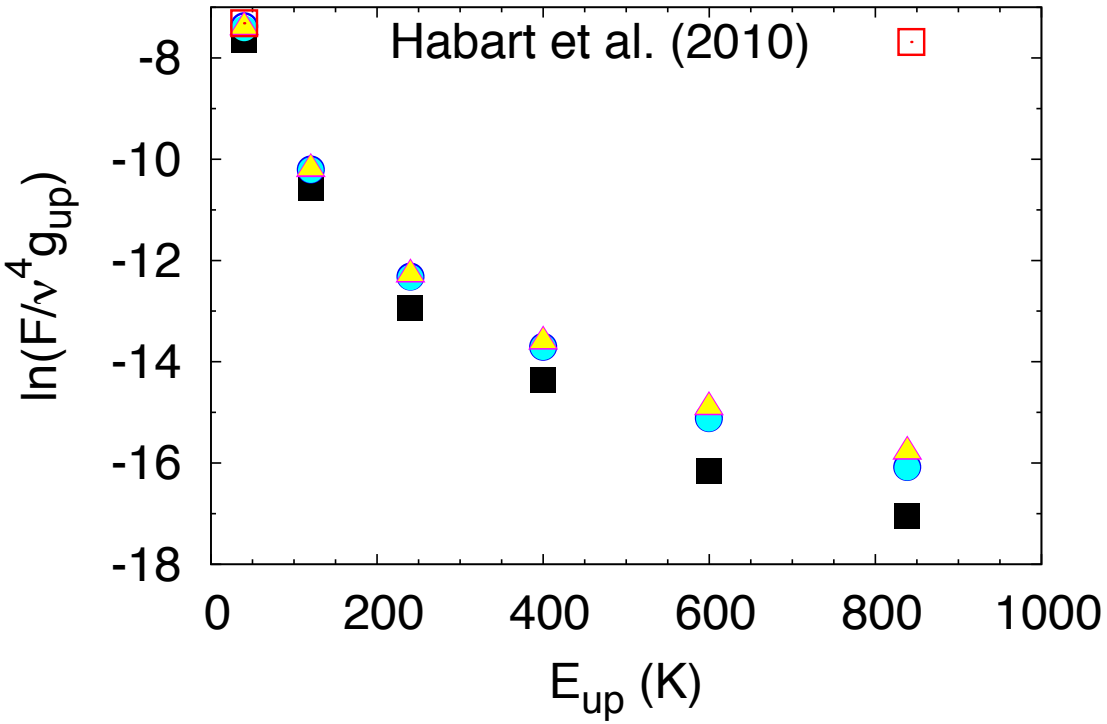
- radiative pumping inefficient



- chemical pumping dominant : $J \geqslant 3-2$
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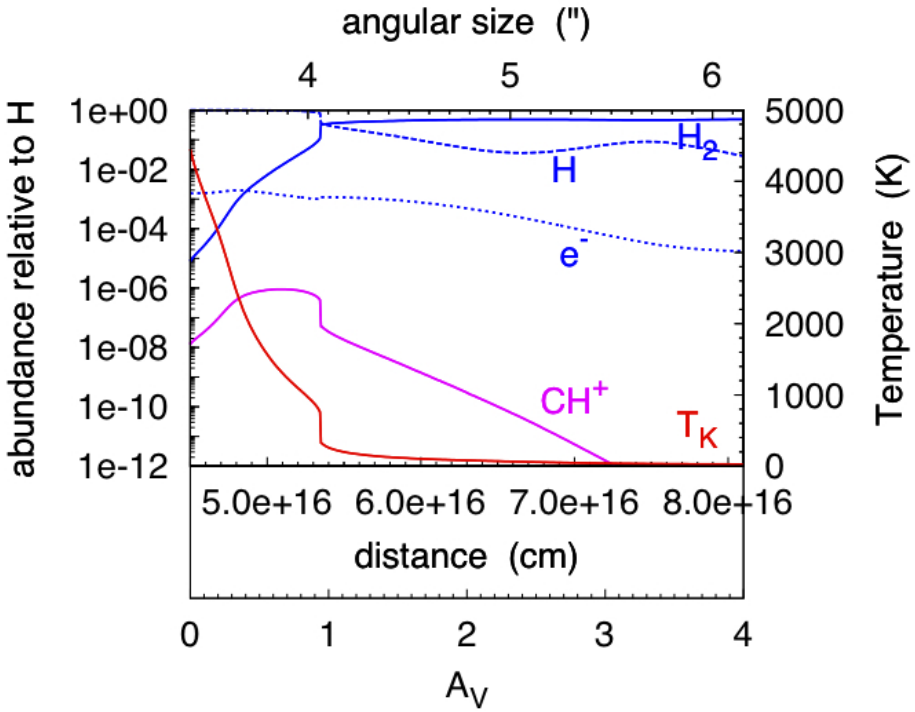
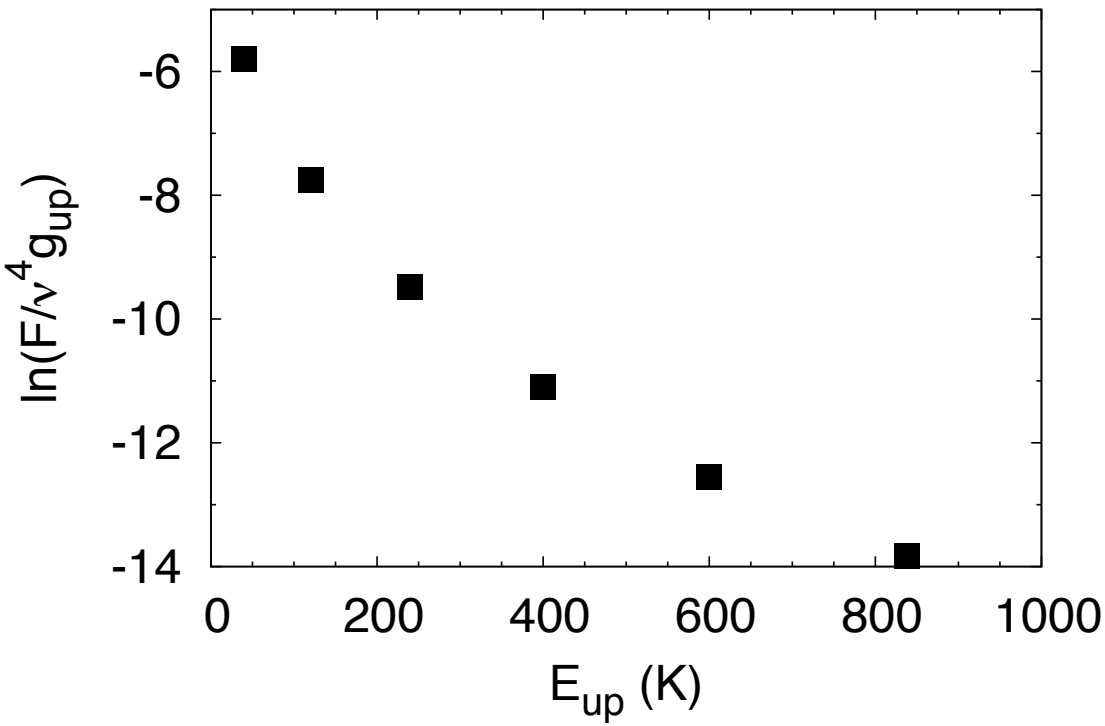
- radiative pumping inefficient

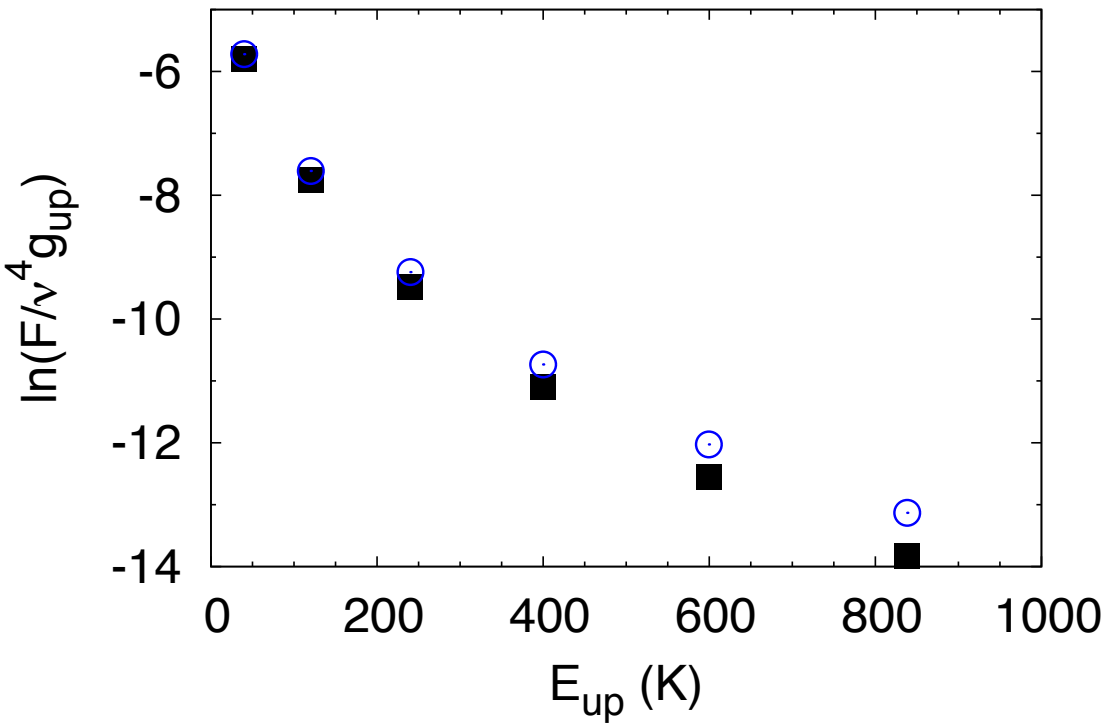
physical conditions

- $n_{\rm H} = 2 \times 10^5$ cm^{-3}
- $\chi_{\rm nir} = 2 \times 10^5$
- $\chi_{\rm opt} = 4 \times 10^4$
- carbon rich
  $[{\rm C}] = 1.3 \times 10^{-3}$

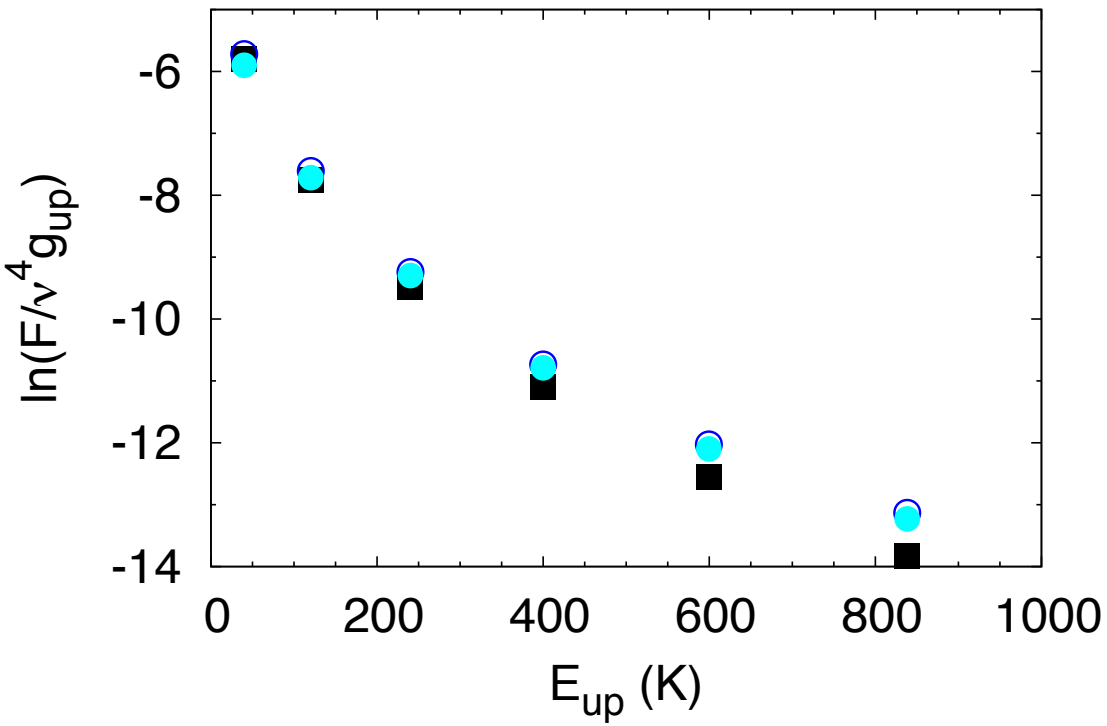
chemical profiles




-6
-8
-10
-12
-14
ln(F/ν4gup)
0
200
400
600
800
1000
Eup (K)



- chemical pumping dominant : $J \geqslant 5-4$
- collision with e^- : $J \leqslant 4-3$



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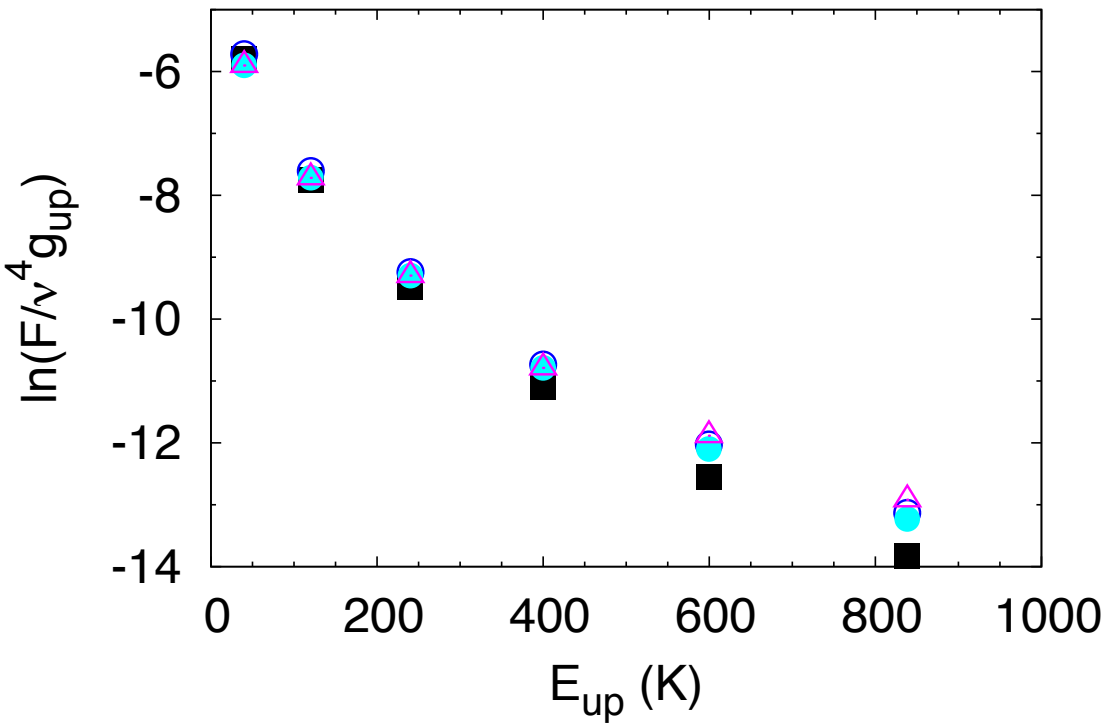

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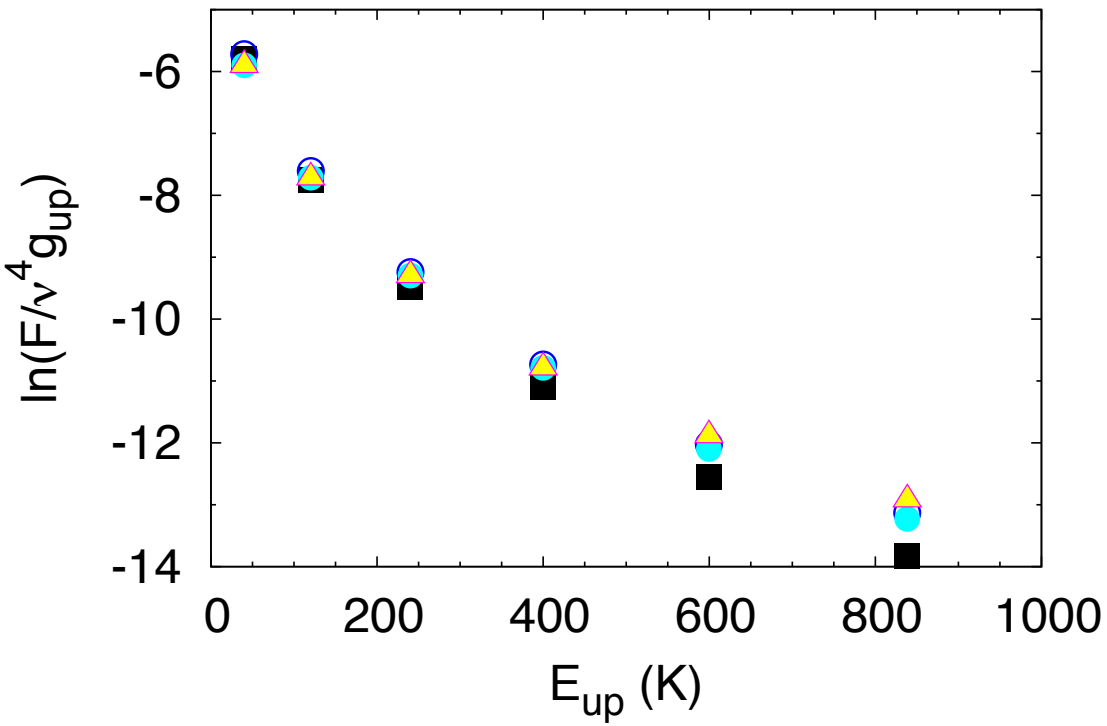

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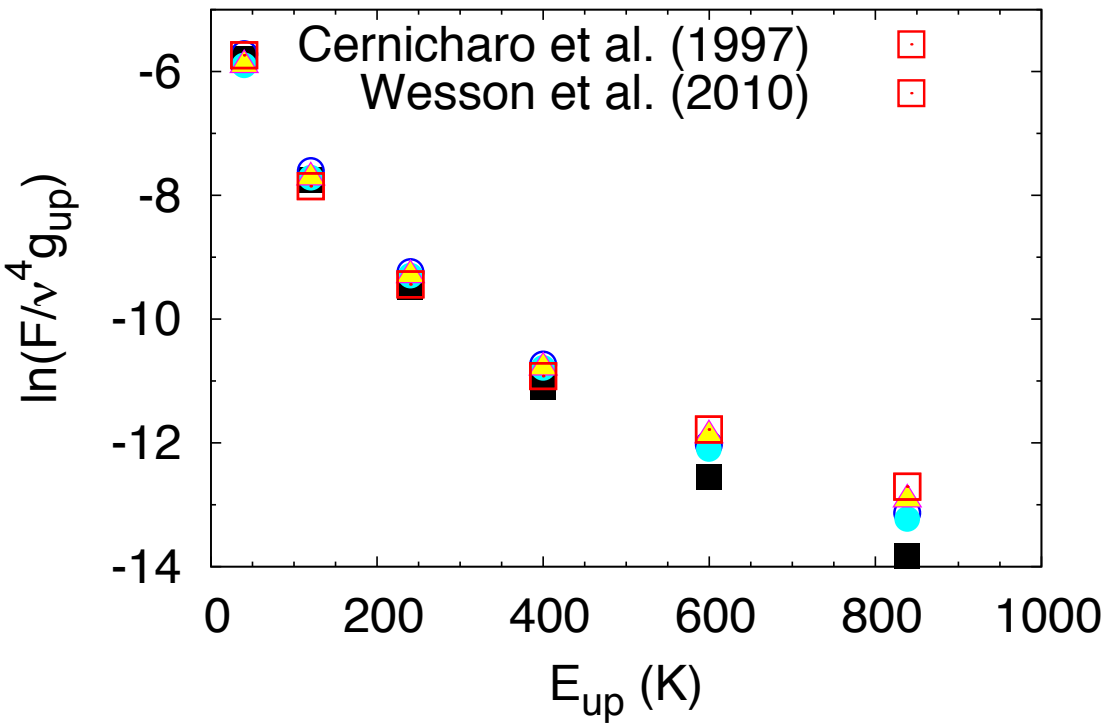
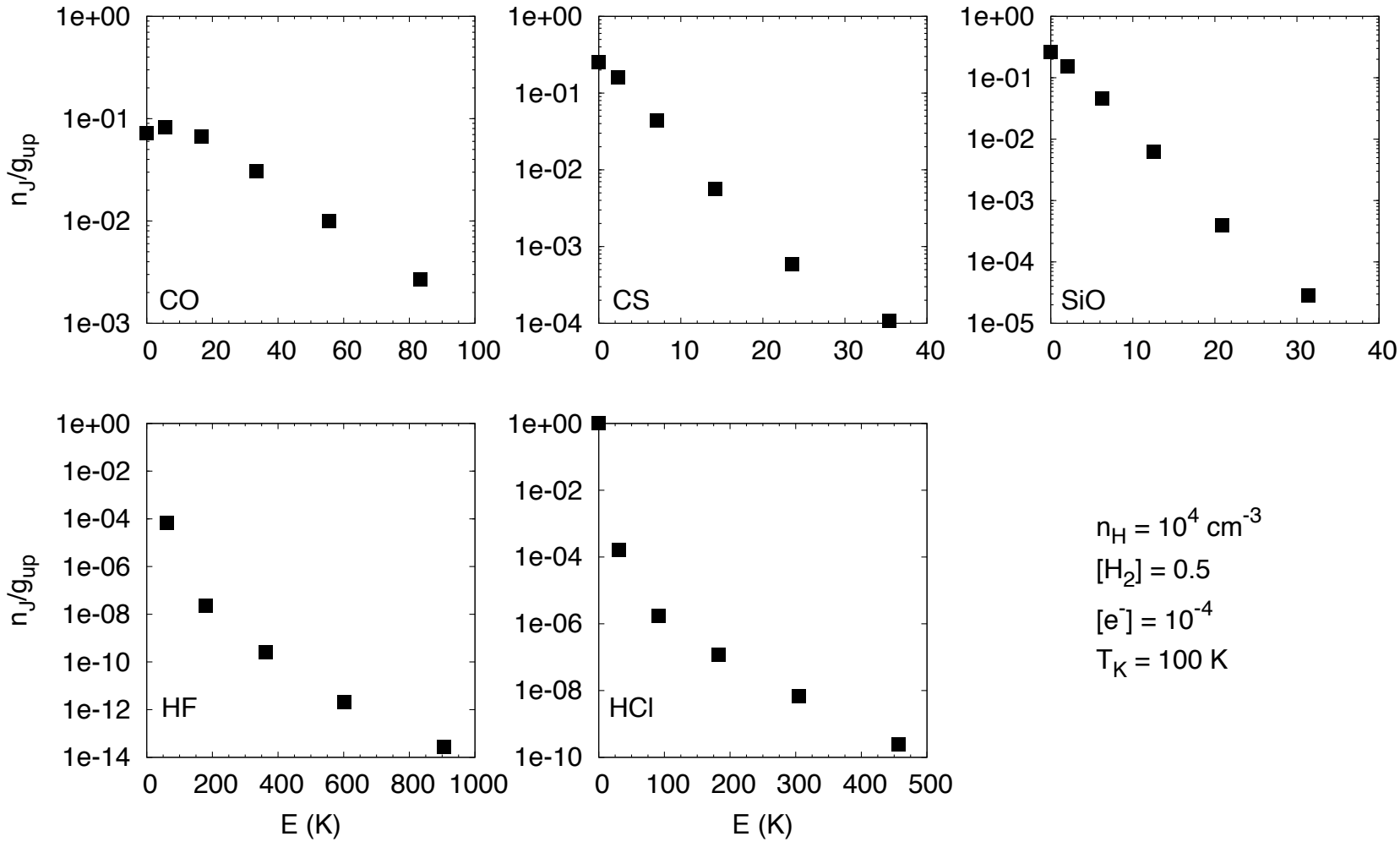
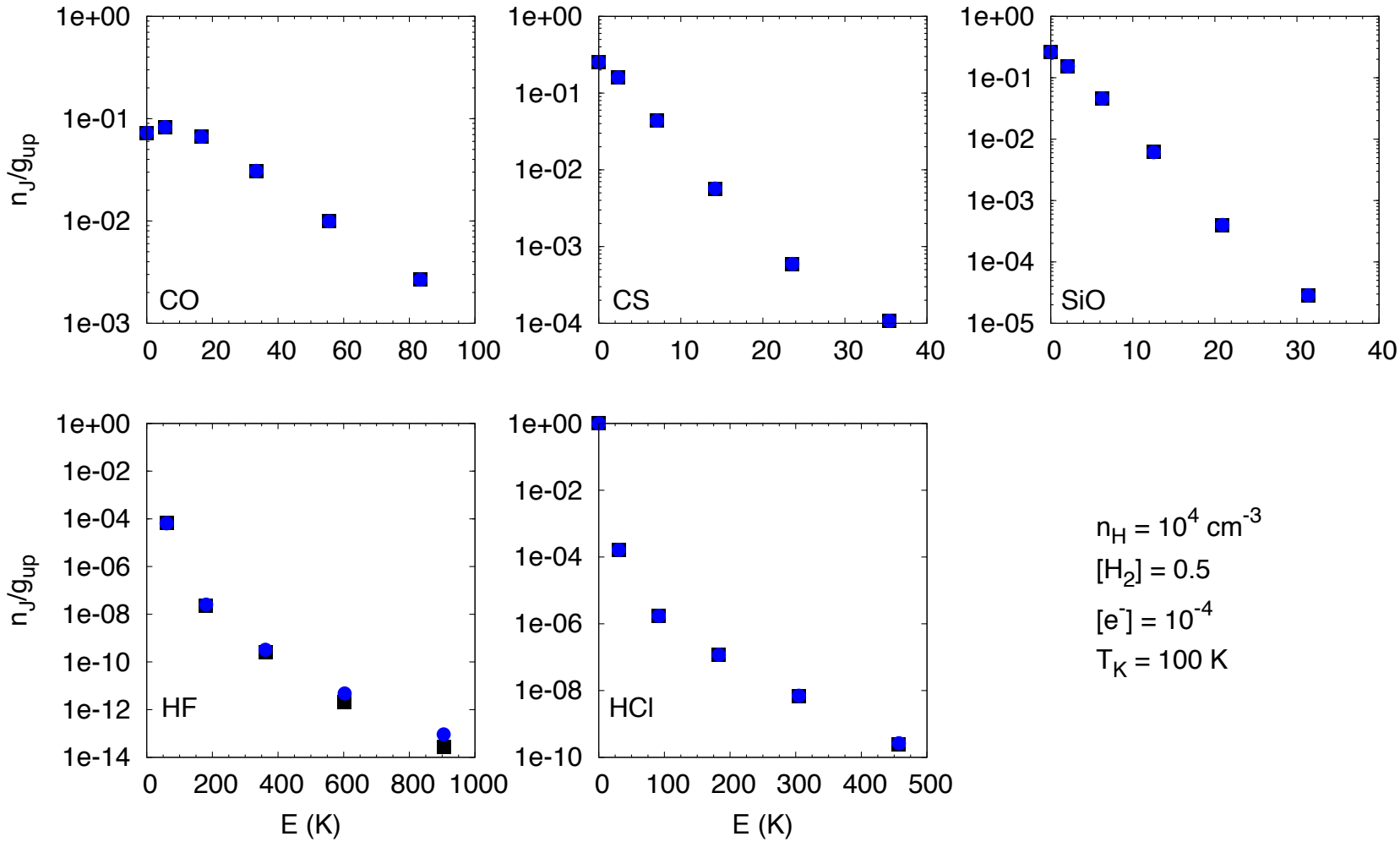


- chemical pumping dominant : $J \geqslant 5-4$
- collision with e^- : $J \leqslant 4-3$
- radiative pumping inefficient
- density 10 times smaller than previous models


CO
CS
SiO
HF
HCl
n_J/g_{up}
E (K)
$n_H = 10^4$ cm^{-3}
$[H_2] = 0.5$
$[e^-] = 10^{-4}$
$T_K = 100$ K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n_J/g_{up}
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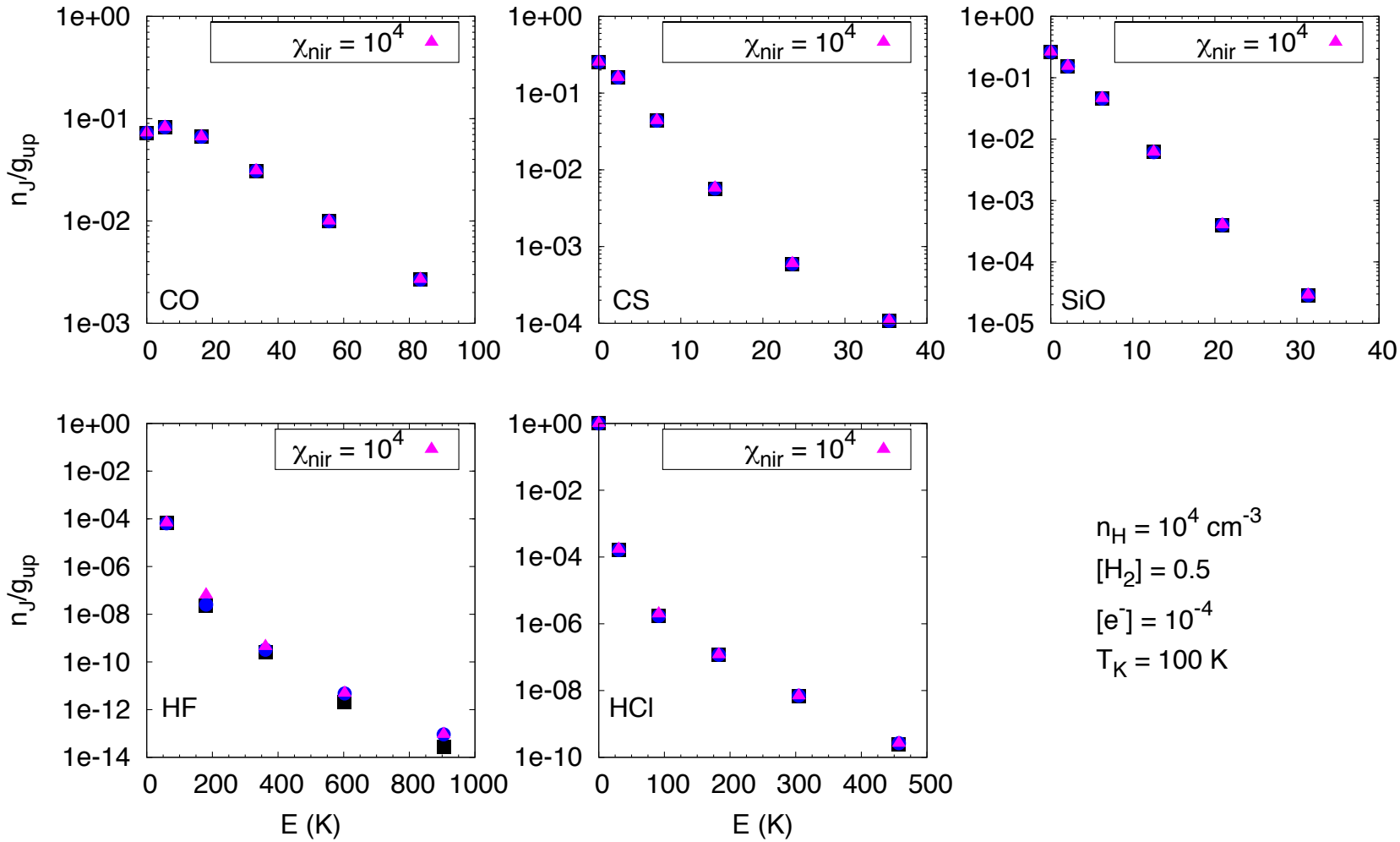
CO
CS
SiO
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n_J/g_{up}
E (K)
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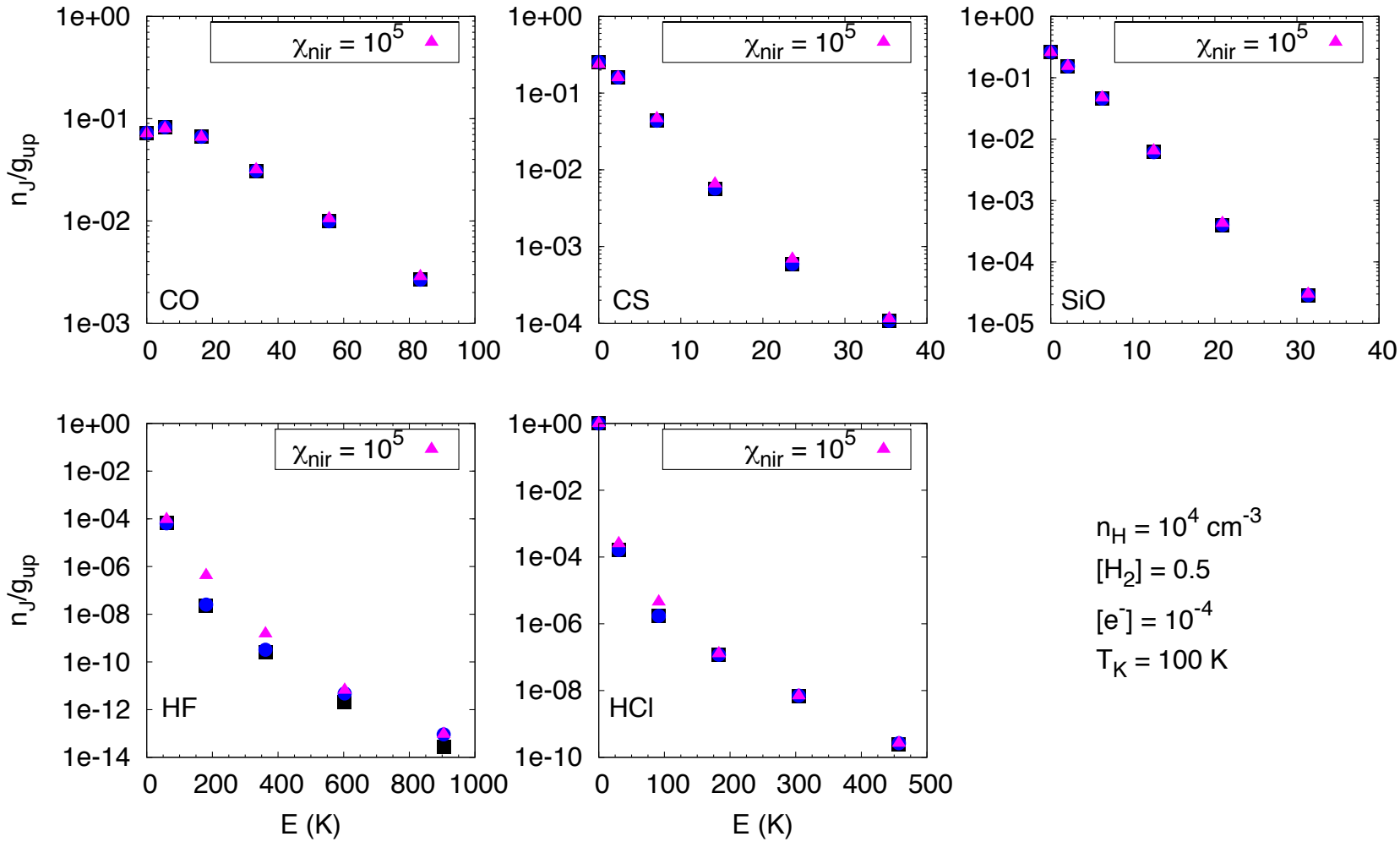
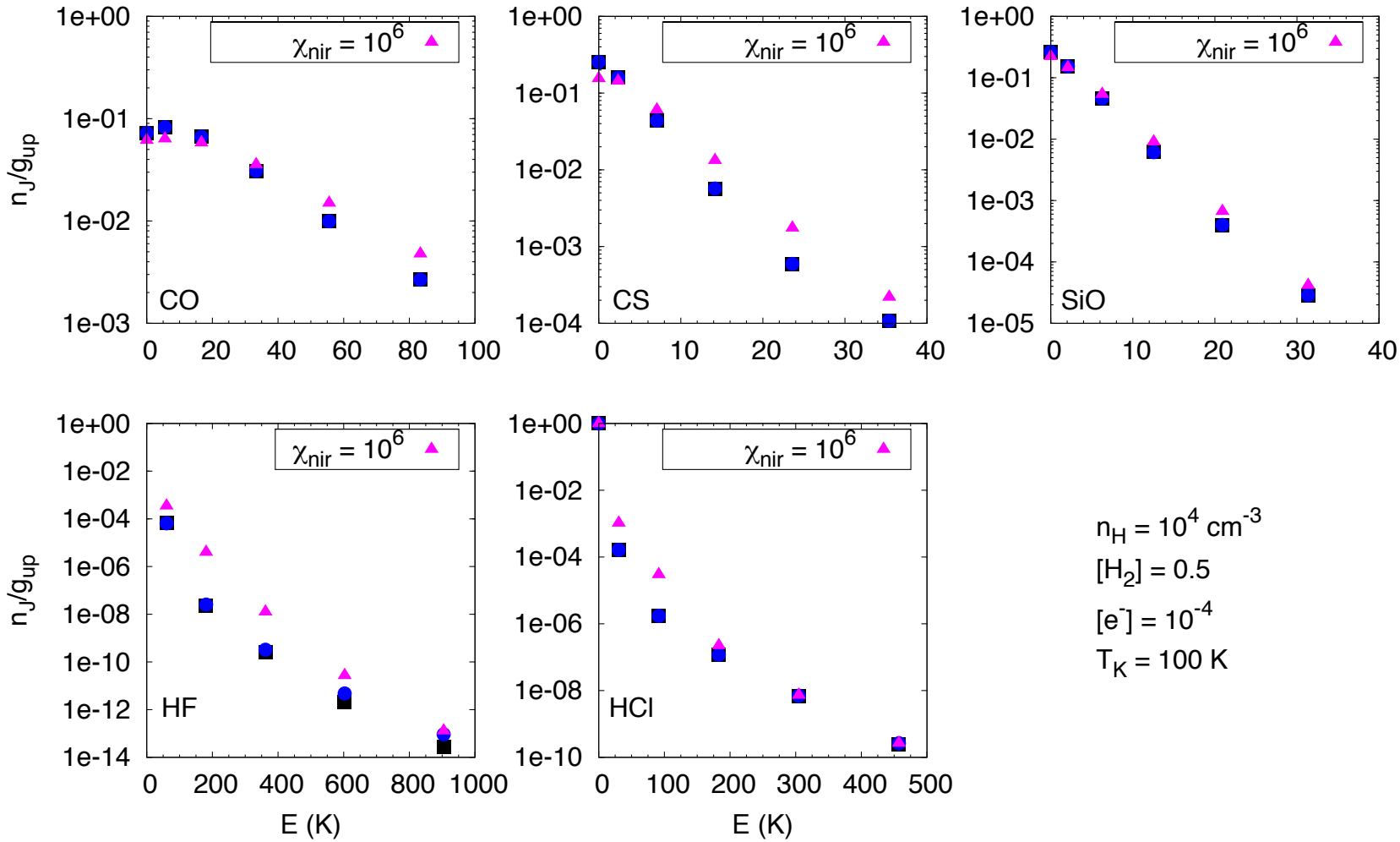


$n_H = 10^4$ cm^{-3}

$[H_2] = 0.5$

$[e^-] = 10^{-4}$

$T_K = 100$ K

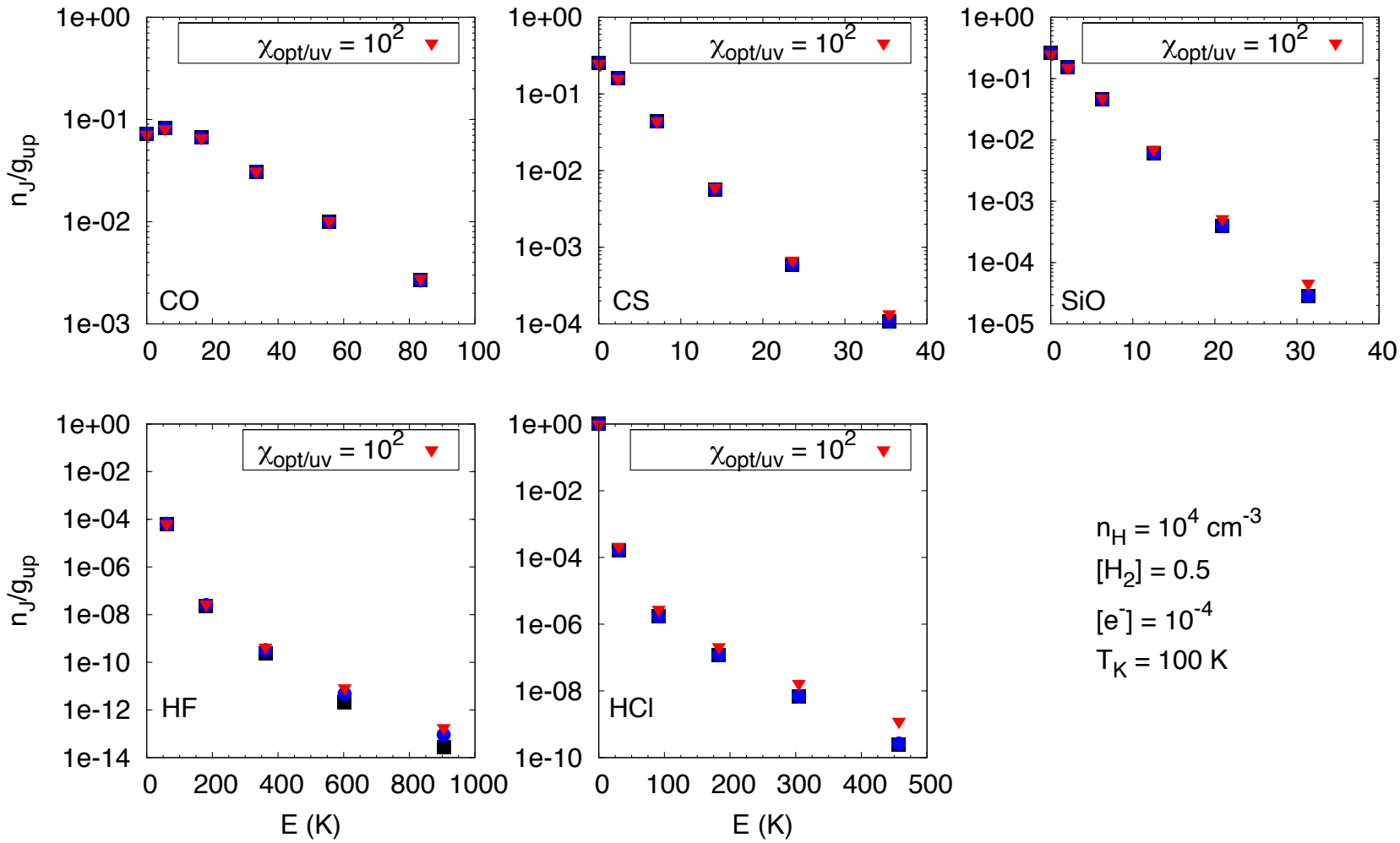


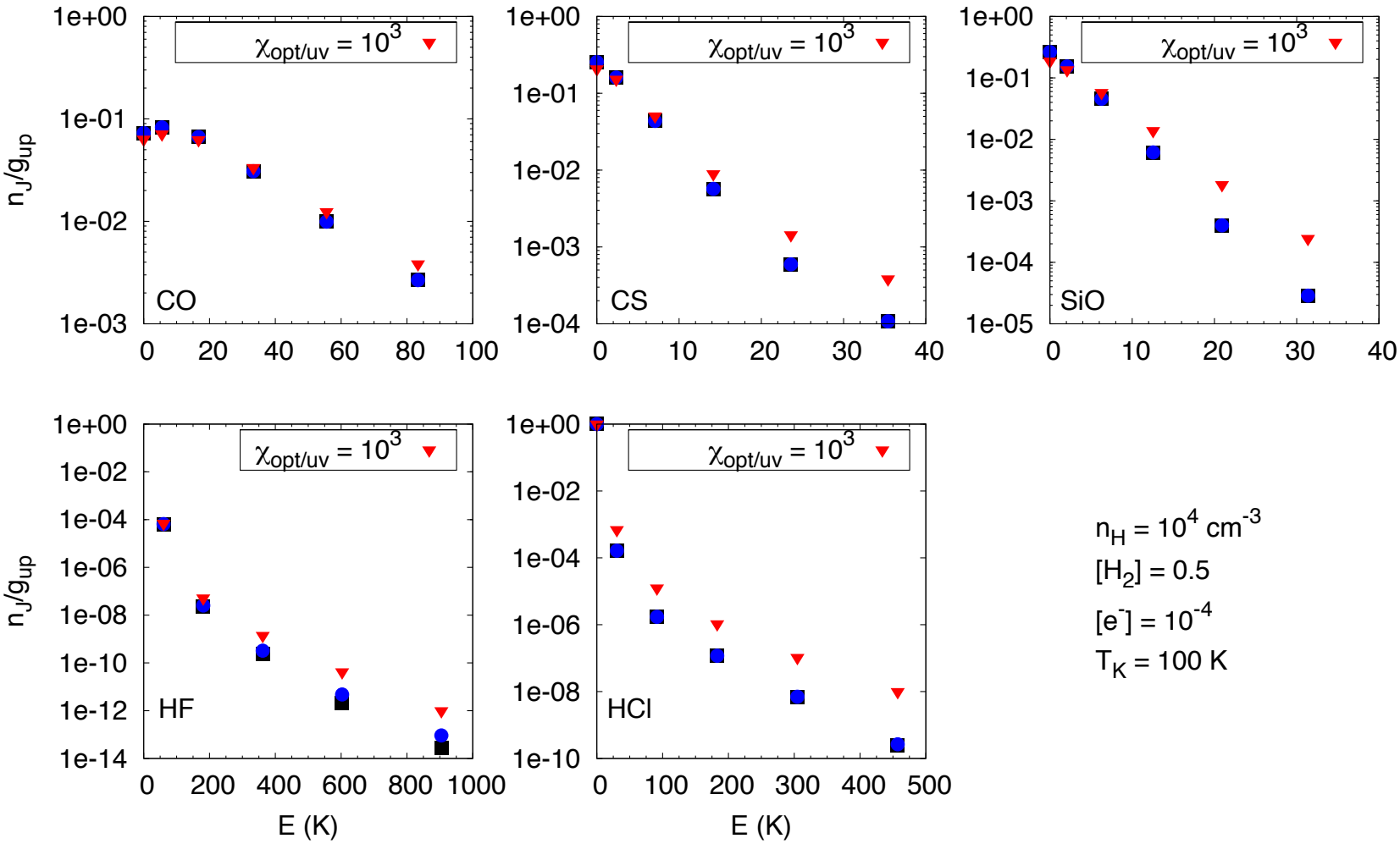
$n_H = 10^4$ cm^{-3}

$[H_2] = 0.5$

$[e^-] = 10^{-4}$

$T_K = 100$ K


χopt/uv = 10^2
CO
CS
SiO
HF
HCl
nJ/gup
E (K)
nH = 10^4 cm^-3
[H2] = 0.5
[e-] = 10^-4
TK = 100 K



$n_H = 10^4$ cm^{-3}

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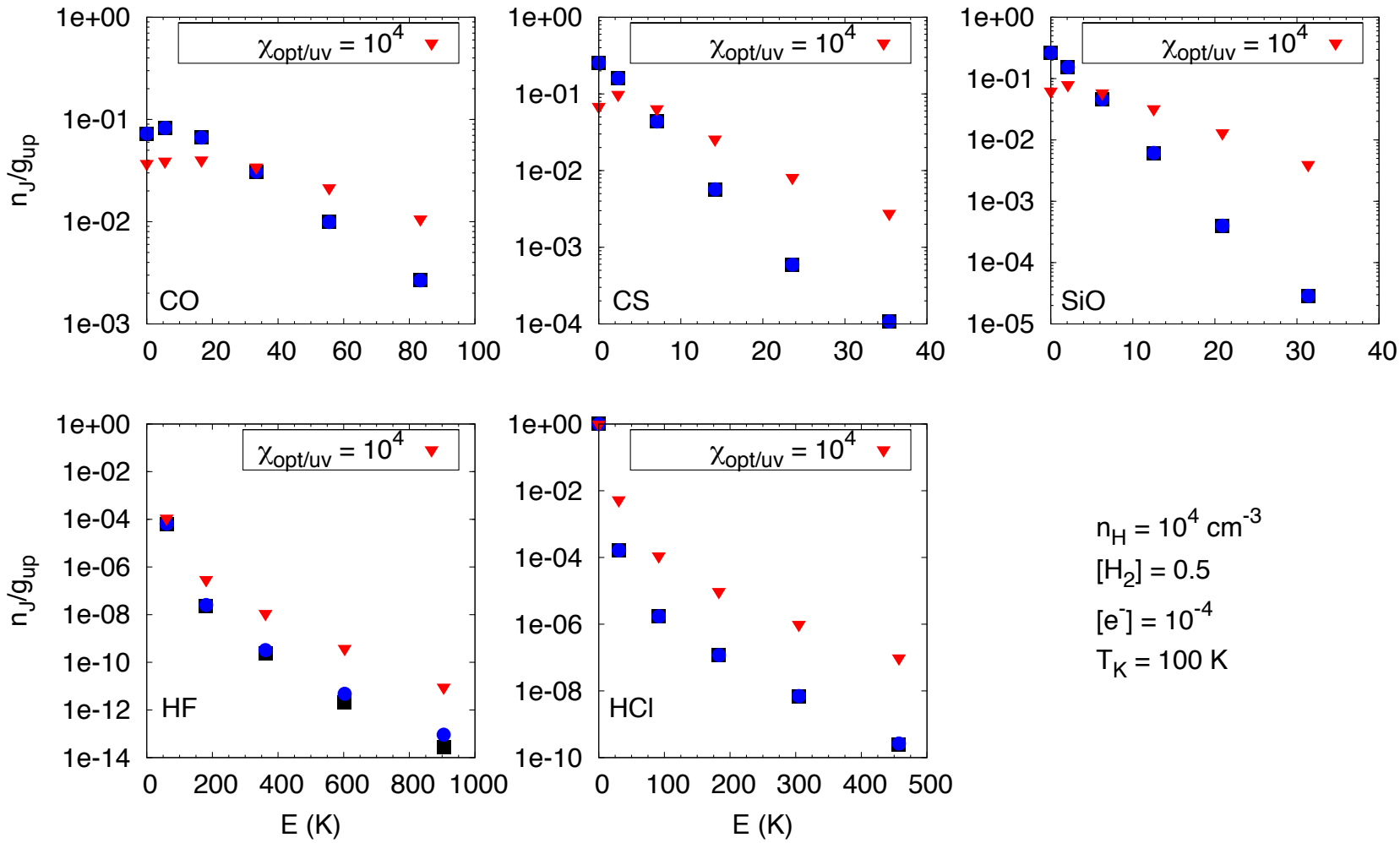

$n_H = 10^4$ cm^{-3}

$[H_2] = 0.5$

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$T_K = 100$ K

Summary

- species sensitive to chemical pumping
  - short lived molecules : e.g. CH^+, CO^+ (?), ...
  - state-specific rate constants are important
  - CH^+ rotational lines explained in low density medium
- species sensitive to near-infrared pumping
  - HF, HCl for $\chi_{\rm nir} \geqslant 10^4 \times (n_{\rm H}/10^4)^{2/J}$
- species sensitive to optical/uv pumping and photodissociation
  - SiO, HCl, CS, and CO for $\chi_{\rm opt/uv} \geqslant 10^3$

Open issues - Future contributions

- extension to ...
  - polyatomic molecules : metastable lines of NH_3
  - other ground-state configurations : OH ($^2\Pi$) and CO^+ ($^2\Sigma^+$)